December 2006

WHRP REQUEST FOR PROPOSAL

Joint Project with the Flexible and Geotechnical TOCs

I. PROBLEM TITLE

Evaluation of Intelligent Compaction Technology for Densification of Roadway Subgrades and Structural Layers

II. BACKGROUND AND PROBLEM STATEMENT

Roadway systems are dependent upon achieving proper compaction throughout the supporting soil subgrades and pavement structures in order to achieve the desired performance. Historically, the support quality of compacted subgrades and pavement structures has been specified as a function of the relative compaction density. This density varies with several items including compaction energy, material characteristics, temperature, water content, etc. for a given material. The objective of achieving a specified level of compaction density is to obtain adequate stiffness and strength and minimize future long-term property changes. In current practice, achievement of adequate density is judged by either visual means (typical for subgrades and embankments in Wisconsin) or discrete in-situ density measurements completed by nuclear density testing. Emerging Intelligent Compaction (IC) systems monitor layer stiffness during compaction by instrumenting the compaction equipment and gauging the reaction of the material being compacted. IC presents an opportunity to continuously monitor/document layer stiffness at the time of compaction, thus producing more uniformly-compacted material layers and allowing real-time compaction modifications based on outputs.

Intelligent compaction technology has been in existence for several years. IC technology provides real-time, in-situ material stiffness information that can be used by project manager/contractor personnel as a basis to make timely databased decisions, while also providing necessary documentation. Multiple manufacturers make Intelligent Compaction equipment with varying outputs and controls.

This technology also has the potential to impact warranty pavement contracts. These contracts are a recent innovation that transfer some risks to the contractors who construct the pavement system. There has been concern over determining the relative compaction of lower material layers because their properties influence the service life of the upper pavement layers. If there is uncertainty regarding support below the pavement layer, contractors accept more risk for the long-term pavement performance through the warranty, resulting in a higher bid price. Thus, adoption of IC technology has the potential of lowering the costs and enhancing the quality and service life of pavement systems by providing the contractor documentation of lower layer compaction levels.

III. SCOPE

There are several main goals associated with this study. The overall goals are to provide the Department with the necessary information to determine if Intelligent Compaction is valid and accurate, identify its advantages and limitations, determine if it can accommodate differing material types and conditions and provide recommendations to the Department. These will allow the Department to analyze the information and make an informed decision on any useful applications.

Work will involve providing a detailed literature review and summary of related research regarding methods and specifications of Intelligent Compaction used in upper Mid-Western State DOTs. This will include gathering information from intelligent compactor manufacturers on available equipment, its outputs, operation, limitations, correlations to measured compaction levels, etc.

Establish the accuracy and quality of the relationships of the measured compaction equipment output values versus measured in situ soil response in terms of stiffness (or modulus) and compare to values of relative compaction density. Nuclear density testing will be used as the benchmark for this comparison. The researcher may elect to use additional density/stiffness measurement methods. The research will provide guidance to ensure the proper interpretation of measured parameters. The interpretation of IC data, which is a material stiffness record, may require consideration of the appropriate state of stress and strain amplitudes when relating to relative compaction density. Appropriate strain levels need to be considered based on the different test methods and traffic loads. Compacted soils may also yield non-uniform modulus distribution due to increasing confining pressure and non-homogeneous density distribution. The research will identify trigger output values corresponding to adequate, or inadequate, levels of compaction, dependent on soil type and moisture level. The research will investigate the effect of differing soil types and moisture conditions on outputs and compaction levels.

Perform field testing to aid in developing the relationships between equipment outputs and levels of compaction. Field testing will address various materials including differing soil types, base courses and Hot Mix Asphalt (HMA). Work will include designing/developing appropriate field instrumentation equipment test programs as necessary. Perform pertinent laboratory testing for material classification and correlation to IC outputs.

Analyze the data to determine if modulus values can be developed using IC output values (and correlations to other parameters) for the various types of material layers under varied conditions. If this is possible, these values can be used in the mechanistic-empirical pavement design procedures.

Provide recommendations for future Departmental use. Identify potential problems and limitations of the technology. Determine the influence of soil moisture and present a recommended field moisture measurement program.

All data, findings, analyses and recommendations will be presented in a final report.

IV. SPECIFIC RESULTS, FINDINGS, TOOLS, ETC.

This research effort will produce needed data and analyses to determine how IC technology and outputs relate to the results found through existing compaction testing. Methods to relate equipment outputs (stiffness, modulus) to compactive levels will be determined and provided. Results and recommendations will be presented for differing test materials (soils types, granular bases, asphalt) and conditions (moisture levels, temperatures, etc.). Advantages and limitations of this technology will be provided. Results will allow the Department to determine if this technology is promising. A final report documenting all research findings and conclusions, will be required. Implementation of IC would require revisions to several WisDOT publications.

V. LENGTH OF RESEARCH PROJECT AND APPROXIMATE COST

It is estimated that that the time required for this project should not exceed 24 months. The cost is estimated to be $100,000, and will be equally split between the Geotechnical and Flexible Pavement TOCs. As part of the researcher selection criteria, the TOCs will evaluate the time and cost estimates in the submitted research proposals. There may also be interest in this project from the Midwest Regional University Transportation Center (MRUTC) and/or the UW-Madison Construction and Materials (C & M) Support Center.

VI. URGENCY AND POTENTIAL BENEFITS

This study will determine if the adoption of Intelligent Compaction technology is an accurate and viable option to replace existing compaction control methods and would benefit the Department. Incorporation of this technology offers the following benefits:

Provides contractors and Department personnel with a rapid methodology (and documentation method) to establish uniformity and quality of compaction operations and make timely informed construction decisions. These timely decisions help speed construction operations, help limit construction disputes and reduce project costs.

Provides a method to *continuously* measure the compaction/stiffness of roadway materials. This helps ensure layers of uniformly compacted materials, which results in increased pavement longevity and enhanced performance.

Provides contractor and Departmental personnel assurance of adequate compaction of roadway materials, thereby reducing the risk (and cost) of pavement construction warranties. Contractors can use Intelligent Compaction as a tool to help evaluate the potential risk on warranted pavements.

Results may assist in providing modulus values that can be entered into mechanistic-based pavement design procedures.

VII. ADDITIONAL REQUIREMENTS FOR IMPLEMENTATION

Results from this study will provide the Department with necessary information to determine if Intelligent Compaction provides us the assurance of adequate compaction of subgrade and pavement materials. Provided information will detail the accuracy of measurement, compare results to current density measurements (nuclear), compare in different soil types and moistures and validate the IC concepts. Review of research results may lead to changes in Departmental practices. These changes may require revisions to the Standard Specifications, Construction and Materials Manual and/or the Facilities Development Manual. This work is beyond the scope of this research effort.

WHRP_IntComp.doc

Intelligent Compaction of Pavements

Prepared for
Wisconsin Highway Research Program
Flexible Pavements Technical Oversight Committee

November 20, 2006

Transportation Literature Searches are prepared for WisDOT staff and principal investigators to heighten awareness of completed research in areas of current interest. The citations below are representative, rather than exhaustive, of available studies on the topic. Primary online resources for the literature searches are the Transportation Libraries Catalog (TLCat), the Transportation Research Information Service (TRIS Online), National Transportation Library (NTL), Research in Progress (RiP) Compendex/Engineering Village, Web of Science, and other academic and scientific databases when requests merit. Online copies of publications are noted when available. Hard copies of cited literature may be obtained through the WisDOT Library; contact John Cherney at john.cherney@dot.state.wi.us or 608-266-0724.

SUMMARY
Our search of the above databases found 10 reports, articles and research projects devoted to flexible pavement applications of Intelligent Compaction technology. Of these, six articles are drawn from trade journals and newsletters, one report from a federally funded source – the Transportation Research Board – and another from an industry conference. The final two entries, below, are to research in progress funded by the Minnesota Department of Transportation and the Virginia Transportation Research Council, respectively.

KEYWORDS
asphalt, intelligent, compaction, flexible, pavement

CITATIONS

Title: Factors affecting compaction of Asphalt Pavements
Author(s): Transportation Research Board
Date: September 2006
Doc ID/URL: *Transportation Research E-Circular No. E-C105*, Washington, D.C.: Transportation Research Board, September 2006. http://onlinepubs.trb.org/onlinepubs/circulars/ec105.pdf.
Description: 190 pp.
Contents: An all-day workshop at the 84th Annual Meeting of the Transportation Research Board (TRB) addressed asphalt practitioners' concerns related to specifying and achieving density during hot-mix asphalt (HMA) pavement construction. The workshop was divided into four mini-sessions with the following themes: Optimizing HMA Construction Temperatures; Recent Advances in Compaction Equipment, Including "Intelligent Compaction"; Longitudinal Joint Density; and Incentives-Disincentives for Construction Quality. The papers in this document are invited papers for this workshop.

Title: Intelligent compaction: The next big thing?
Author(s): Dick Kronick
Date: Fall 2006
Doc ID/URL: *Technology Exchange* (Newsletter of the Minnesota Local Technical Assistance Program), Vol. 14 (4), Fall 2006: 1, 4. http://www.mnltap.umn.edu/publications/exchange/2006-4/2006-4-1-1.html.
Description: 2 pp.
Contents: This article describes three methods and equipment for intelligent compaction of soil and asphalt at sites in Minnesota, and its information is drawn from pages 12-13 of *Minnesota Pavement Conference: Session Summaries* (St. Paul, Minn.: University of Minnesota, LTAP, Feb. 16, 2006), which can be viewed at http://www.mnltap.umn.edu/pdf/2006PaveConSummary.pdf.

Title: Automating asphalt compaction
Author(s): Dan Brown
Date: June 2006
Doc ID/URL: *Public Works*, Vol. 137 (7): 62-63. http://www.pwmag.com/industry-news.asp?sectionID=770&articleID=314714.
Description: 2 pp.
Contents: This article describes the state of automated asphalt compaction in terms of the improving technology in that field. As more complicated specific densities are necessary as asphalt technology improves, rollers are faced with a dilemma between increasing vibrator impact and the requisite speed with which this compaction must be made. The use of intelligent compaction systems is also discussed, which essentially monitor the stiffness of the hot mix asphalt (HMA) being laid and using that information in the compaction process. Drum physics are important to this process as well, as increasing demands on compaction specificity require more precision in the tools used. The author also writes of the soon-to-be-merged intelligent compaction technologies with global positioning systems (GPS), which has already begun to take shape in Europe.

Title: Asphalt construction: A window to the future
Author(s): Dan Brown
Date: 2006
Doc ID/URL: *Asphalt*, Vol. 21 (1): 22-26.
http://www.asphaltmagazine.com/singlenews.asp?item_ID=999&comm=0&list_code_int=MAG01-INT.
Description: 5 pp.
Contents: More performance-based specifications and design-build projects will allow for greater freedom in hot mix design and construction methods. Contractors will complete large milling and resurfacing projects in record times. There will be more knowledge-based systems for delivering mix to projects, and pavers will become more automated and operator friendly. Global Positioning Systems and intelligent compaction systems will enable asphalt compactors to measure density on the go, and then send the information to an analysis center which will return information telling the roller where more compaction is needed. Warm mix asphalt will extend the paving season on both ends. The use of material transfer vehicles to remix and move asphalt from trucks to the paver will increase and, as a result, smoothness and quality control will improve. This article discusses these and other changes expected to occur in the future of asphalt construction. Specific topics covered include construction innovations, tracking and communications, intelligent paving, more uniform mix, and intelligent compaction.

Title: Computer methods in intelligent compaction
Author(s): R. Edward Minchin, Jr., David C. Swanson, H. Randolph Thomas
Date: 2005
Doc ID/URL: *Proceedings of the 2005 ASCE International Conference on Computing in Civil Engineering*, 2005: 1145-1155.
Description: 11 pp.
Contents: The term "intelligent compaction" is now heard often enough to make one believe that the method used for documenting the quality of hot-mix asphalt pavement has evolved to a more modern state than is actually the case. In fact, the current process for determining the density of an asphalt mat uses 1960's technology. The nuclear density gauge was a major break through in the mid-1960's and quickly became the state-of-the-art for measuring asphalt density. It revolutionized the asphalt paving industry because it allowed the owner of the project to check the density of the asphalt mat much more quickly than methods used up to that time. That ability, coupled with improved asphalt production methods led to tremendous increases in constructor productivity. Now, however, the owner rarely checks the density of the asphalt mat during the paving and compaction process. The responsibility for quality control (QC) of the paving and compaction process has largely been given to the contractor. This shift in responsibility comes at a time when the construction industry as a whole is faced with the worst labor shortage in history, limiting the number of qualified QC technicians and equipment operators. Recently, researchers introduced a patented system that, when mounted on a vibratory asphalt compactor, can render an asphalt density reading (in pounds per cubic foot) every one-second in real-time. Details of the system and its successes and limitations have been documented in the literature. This paper briefly describes the system and details the essential contributions made by computer hardware and software to a successful onboard asphalt density measuring system.

Title: New mixes alter compaction technology
Author(s): Tom Kuennen
Date: September 2004
Doc ID/URL: *Better Roads*, Vol. 74 (9), September 2004: 32-46.
http://obr.gcnpublishing.com/articles/sept04a.htm.

Description: 13 pp.
Contents: New asphalt mix designs complicate rolling. Fortunately, a new generation of compactors is evolving which can provide ultra high vibration, and vary amplitude (force) with vibration (frequency) according to the type of asphalt and aggregate being placed, thus avoiding dangerous over-compaction. Key to the success of these equipment lie on the ability of the operator to balance the demands of new mixes and equipment technologies against the vicissitudes of weather, variations in plant mix, and out-of-spec mixes caused by nothing more than traffic jams, and still make the pavement come out perfect.

Title: Never guess again: Intelligent compaction making precision commonplace at the jobsite
Author(s): B. Wilson
Date: August, 2004
Doc ID/URL: *Roads and Bridges*, Vol. 42 (8): 22-25.
http://www.roadsbridges.com:80/rb/index.cfm/powergrid/rfah=|cfap=/CFID/3211407/CFTOKEN/89068603/fuseaction/showArticle/articleID/5396.
Description: 4 pp.
Contents: This article focuses on intelligent compaction systems that take the guesswork out of soil or asphalt compaction. These systems automatically measure and control the energy output of a roller's drum. Although each manufacturer's system has its own specific method of execution, they all generally function in the same way by measuring and reacting to the changing stiffness of the material being compacted. The compaction systems use devices such as accelerometers to measure both the horizontal and vertical reaction of the drum to the material it is compacting. The systems then actually control the output of the drum. The process, which is known as vectoring, involves a microprocessor that calculates the accelerometer's gathered data and then redirects the energy of the drum to avoid over-compaction. Several of these intelligent compaction systems also include an asphalt mat temperature sensing capability that help in achieving error-free applications. Additional benefits associated with intelligent compaction systems include a longer service life for equipment, increased efficiency, and the documentation of jobsite results through on-board printers.

Title: Making a difference
Author(s): A. Peterson
Date: 2002
Doc ID/URL: *World Highways/ Routes du Monde*, Vol. 11 (8): 34-35, 38, 41-42.
Description: 5 pp.
Contents: Proper compaction is essential in ensuring a durable road surface. This article describes the major types of compaction rollers available, and the benefits and drawbacks of each. Vibratory asphalt compaction rollers are the most widely used. Although vibratory rollers work well for the normal thickness of a traditional asphalt wearing course, they are less suitable for compacting thinner stone mastic asphalt wearing courses. The combination of low frequency and high amplitude needed to achieve the desired density and depth of compaction for thicker layers has a tendency to over-compact thinner layers and crush their larger aggregates. An oscillating roller, which provides a horizontal alternating sheer force to achieve faster compaction, has been developed for bridge decks and other surfaces where the power of a vibratory roller can be harmful. Static rollers are also available. One promising new development is an "intelligent" roller that can monitor and adjust the amplitude according to the soil type and desired degree of compaction.

RESEARCH IN PROGRESS

Title: Field Validation of Intelligent Compaction Monitoring Technology for Unbound Materials and HMA
Principal Investigator(s): Thomas Cackler, Center for Transportation Research and Education
Start Date: October 15, 2005
RIP URL: http://rip.trb.org/browse/dproject.asp?n=11386.
Sponsor Organization: Minnesota Department of Transportation
Contents: New intelligent compaction technology will be evaluated at several test sites in Minnesota with the objective of increasing earthwork and asphalt pavement quality through more efficient compaction operations and innovative quality control /quality assurance (QC/QA) equipment.

Title: Preliminary Field Investigation of Intelligent Compaction of HMA
Principal Investigator(s): G.W. Maupin, Virginia Transportation Research Council
Start Date: June 1, 2006
RIP URL: http://rip.trb.org/browse/dproject.asp?n=11893.
Sponsor Organization: Virginia Transportation Research Council

Contents: A new roadway construction concept called intelligent compaction, IC, uses rollers that have the ability to change compaction effort as the roller drum senses the stiffness of the layer. If the stiffness measurements recorded by the roller correlate to density as expected, there is potential that the roller might be used as an acceptance tool in the future. This project is designed as a preliminary study to a national pooled fund study and will determine the correlation of density to stiffness and influence of temperature on the ability to achieve adequate stiffness/density.